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XLVIII. *Electrical Experiments, to explain how far the Phenomena of the Electrophorus may be accounted for by Dr. Franklin's Theory of positive and negative Electricity; being the annual Lecture instituted by the Will of Henry Baker, Esq. F. R. S. By John Ingenhoufz, M. D. F. R. S.*

Read June 4,
1778. **H**AVING had the honour of being appointed by the President and Council of the Royal Society to read the annual dissertation on some philosophical subject, instituted by our worthy member the late Mr. BAKER, I have endeavoured to pursue some electrical experiments, to explain how far the *Electrophorus perpetuus* may be accounted for upon the almost generally received theory of Dr. FRANKLIN of positive and negative electricity.

THIS electrical instrument consists of two different pieces; *viz.* 1. a metallic body, in the form of a plate, or any other convenient figure, furnished with an insulating handle, to be used for lifting it up; and 2. a flat non-conducting substance, such as glass, resin, or some

other non-conducting matter, upon which the said metal plate is placed.

This machine, invented by Mr. VOLTA, a learned gentleman of Como, is certainly a valuable acquisition to the Electrical apparatus. Once excited, it is for a long while ready to afford electricity enough for all experiments which do not require a very great force; and it has the advantage of not being so much affected by damp weather as the common machines with glass globes, cylinders, disk, &c. It is very easily put in action by a slight friction with a dry hand, a piece of leather, a rough skin of a hare, a cat, or some other animal. It is as easy to excite with this machine a negative as a positive electricity. It has the advantage of being capable at almost all times of affording at pleasure such a force of electricity as is wanted, even to such a degree, that the metal plate is no longer able to contain all the electric fluid communicated to it; but throws it out every way, either upon the metal upon which the resinous cake is usually fixed, or into the air: and this increase of electrical power is obtained by the easiest means; for instance, by charging with the Electrophore a coated phial, and placing it afterwards upon the resinous cake itself, or upon the metal plate placed upon the resinous cake (provided the metal plate be less in circumference than the resinous

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nous cake, and no metallic communication exist between the metal plate and that metal upon which the cake is fastened). If the knob of the phial, thus placed, be touched by the finger, and then taken away, holding it by the knob, the force of the electrophore is found to be remarkably increased.

But a more pleasing way of increasing the electrical force of this instrument is by transferring alternately the metal plate from one resinous cake to another, and touching it after it is placed upon the cakes. By this method both cakes acquire continually more and more electricity; so that in a short time, by this alternate translation, the metal plate returns from either cake quite overcharged; and thus Leyden phials may be charged by it very strongly, and even so as to break them. It is very remarkable, that by this method the metal plate returns from one cake in a positive, and from the other in a negative state.

This manner of increasing the two electricities was found out by my learned friend Dr. KLINKOCH, professor in the University of Prague, soon after I had given him a description of this new instrument, which I had received from his Royal Highness the Arch-duke FERDINAND a very little while after Mr. VOLTA had invented it.

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It is true, that Father BECCARIA had a long while ago excited an electricity, almost perpetual, by two panes of glass, one placed upon the other, each having but one metal coating, and joined together so that no metal was placed between the two glasses. These two glasses being applied to a prime conductor of an electrical machine, so as to receive a charge in the same way as one glass coated on both sides is to be charged, afford numberless sparks from both coatings, after the two glasses have been discharged in the common way, by making a communication between the two coatings.

In order to produce these sparks, the two glasses must be separated from one another, so as to avoid touching the coatings in the moment of separation. Each of the coatings will give a spark, which may be repeated after having replaced the two glasses one upon another. After the two glasses have been thus joined again, and touched after their conjunction, another spark is obtained from both after their separation; and these sparks may be thus repeated almost *ad infinitum*; so that these two glasses, once excited, seem to be an unexhausted source of electrical sparks. Father BECCARIA calls this experiment *electricitas vindex*. Whether this denomination be a proper one to convey some idea of what is understood by it, I will not now undertake to determine.

The same Father BECCARIA had also found, that the coating of a glass, after being discharged, was able to give new signs of electricity, when taken off by means of silk strings.

Some other experiments were made many years ago by Mr. CIGNA of Turin, and by some other electricians, which have a great deal of similarity with the electrophore.

But as the inventors of these experiments did not adapt them as an electrical machine, they do not diminish at all, in my opinion, the honour which Mr. VOLTA deserves, for having enriched the electrical apparatus with a very simple and handy machine, continually ready to excite as strong an electricity as is requisite for the most ordinary purpose.

The novelty and simplicity of the machine could not but strike every electrician; I cannot express how much I was pleased with the first sight of it, and with what eagerness I set about endeavouring to understand the nature of it. I analyzed it in various ways: I compared it with Father BECCARIA's *electricitas vindex*, with an ordinary coated glass, and coated resinous electrics.

Some electricians, puzzled with the strange phenomena which it affords, thought it over-turned entirely the almost universally received theory of Dr. FRANKLIN,
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and that it could not be understood but by establishing new principles.

After considering the matter maturely I thought, that these phenomena, though at first sight extraordinary, could be explained by the same principles which were already received by almost every philosopher.

But before I proceed to my intended explanation of the most obvious phenomena of the electrophorus, I must beg leave to set down some constant laws, which nature observes in the various motions of the electric fluid, and to which electricians do not seem to give a sufficient attention.

1. The electric fluid exists in all substances, in a certain quantity, which is natural to them.

2. The electric fluid is repulsive of itself, that is to say, each particle of electric fluid tends to recede as far from another particle of the same fluid as it can.

3. The state of electricity of a body is that in which it has acquired more electrical fluid than the neighbouring bodies, or in which it has less of this fluid than the surrounding bodies.

4. In the first case the electrical fluid tends to expand itself through all bodies near it, which can by their nature receive it. In the second case, the electrical fluid of all the surrounding bodies finding less resistance towards
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a body negatively electrified, or having lost a part of its natural share of electricity, rushes towards that body, and tends to diffuse itself through it, and thus to dispose itself into an equilibrium.

5. The reason why the electric fluid, existing every where, seems to remain inactive in the common state of nature is, because all other bodies having their ordinary share of this fluid, an equal pressure exists on all sides. Thus, if all the bodies upon the earth were to acquire more or less of electric fluid at the same time, in equal proportions, no electrical phenomena would be the consequence of such a state; because the pressure being every where equal, the repulsive force of the electrical particles would be every where balanced. Thus two bodies, both negatively or both positively electrified, will not give a spark to one another: they only recede more from one another, because the other surrounding bodies are not in the same situation with them. This assertion seems to be illustrated by Father BECCARIA's electrical well (*puteus electricus*), which is nothing but a metal vessel electrified, in which two cork balls are suspended by silk threads; the balls do not show signs of electricity within the cavity of the vessel, because the electric fluid presses equally on every side.

6. All non-conducting bodies may acquire on each part of their substance more or less of the electric fluid, as well as conducting bodies, at least to a certain proportion; but they do not allow it to pass freely through their substance or over their surfaces.

7. All bodies whatsoever are susceptible of electricity, positive and negative indifferently, either by exciting them by friction or any other way, or by bringing them within the sphere of action of a body already electrical; so that even metals, the best conductors, may be as easily excited by friction, if insulated, as glass or sealing wax. The only material difference between the conducting and non-conducting substances seems to be, that the electricity does not spread itself so easily and so rapidly through or upon those bodies which are non-conductors as upon those which are conductors. An electrical spark thrown upon the surface of a piece of metal insulated, of whatever length it be, diffuses itself equally through the whole mass, if this metal be left to itself out of the sphere of action of another body charged with electricity. The whole electricity communicated by this spark is discharged at once by touching any part of the same metal. On the contrary, electricity seems rather to stick to that part of a non-conducting body to which it is applied, spreading but slowly and unequally over its surface, from
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which it may be taken by degrees, by touching those parts to which it was applied. There are some bodies which seem to be of a middle state between these two, *viz.* through which the electric fluid propagates as through good conductors, but slowly, such as common wood, moist air, and many other bodies. Electricity seems to diffuse itself through these bodies almost as sugar and salt diffuse themselves through water, spreading farther and farther through the liquid.

8. All those bodies, which are non-conductors, seem to acquire a state of electricity with some reluctance; and, after they have acquired it, to hold it more tenaciously, or to part with it with more difficulty, than conductors. One touch takes away all the electricity of a metallic body, but does not absolutely convey away all the electricity of a piece of glass or another electric body, such as sealing wax, amber, &c. The metal plate of an electrophore takes almost no electricity at all from the resinous cake, if it be lifted up without having been touched when it was upon the cake.

9. All resinous bodies, silk and many others, retain more tenaciously their state of electricity than glass, however dry. Thus a piece of glass excited is almost quite deprived of its electricity by a conducting substance

being applied to it; but a resinous body, though touched, retains still a great share of its electricity.

10. A conducting body insulated, being placed within the sphere of action of an excited non-conducting body, or even in contact with it, acquires at the same time two contrary electricities; *viz.* the part in contact, or very near the non-conducting electrified body, acquires a contrary electricity to that of the non-conducting body, at the same time that the opposite or farthestmost extremity is possessed of the same electricity with the conducting body.

11. A conducting body insulated, being in contact with another conducting body excited with either electricity, acquires the same electricity throughout its whole extension, or divides with this body its electricity equally.

12. But an insulated conducting body, being only in the sphere of action of another electrified conducting body, acquires, as in the first mentioned case, two different electricities at the same time; *viz.* towards the electrified body it acquires a contrary electricity, and at the opposite extremity it acquires the same kind of electricity with the electrified body.

It seems therefore to be a law of nature, that the electric fluid which is accumulated upon a body, and finds an
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obstruction in its free passage to another neighbouring body by the interposition of a non-conducting body (such as dry air, glass, &c.) forces by its repulsive power the electric fluid naturally contained in all bodies to the furthest extremity of the neighbouring body, so as to excite in its nearest extremity a kind of defect of the electric fluid, or a kind of vacuum, till at last the accumulation of the electric fluid becomes so great upon the electrified body, that it overpowers the resistance of the intermediate non-conducting substance, forces its way through it, and rushes in the form of a spark upon the neighbouring body..

If the electric fluid be thrown upon the surface of a pane of glass, coated on both sides with a metallic substance, such as tin-foil; the fluid, finding an obstruction to its passage through the body, is crowded upon that surface of the glass which has received it; forces the electric fluid out of the other surface, if some conducting body is near it, or in contact with it, and can convey it away; till this fluid becomes so much crowded upon that surface as to overpower the resistance of the glass, and to force its way through the substance of the glass, in order to diffuse itself upon the other surface, upon which was produced a kind of vacuum. The glass being thus rent is no longer able to be what is called charged; but after the crowded

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electrical fluid of a prime conductor has in the same manner rent the plate of air (which obstructed to a certain degree its free passage between the prime conductor and the neighbouring body) by giving it a spark, the same spark may be repeated at pleasure, because the opening formed by the spark through the plate of air is immediately shut up again according to the nature of all fluids.

If an insulated conducting body be situated in the manner described, so as to possess at its different extremities a contrary electricity, it may impart to any other body brought in contact with it, or within its striking distance, a share of that electricity which it has acquired at its farthest extremity. The former body, so touched, has effectually lost that part of electrical fluid which was in a certain manner crowded upon that extremity; and therefore being taken out of the sphere of action of the excited body, as, for instance, a prime conductor, after having thus lost a part of the electric fluid crowded upon its extremity, is found to possess a negative electricity if the excited body had a positive, and a positive if the excited body had a negative one.

Thus we see how far we must believe what is commonly affirmed as a fact, that a body, plunged in the atmosphere of an electrified body, acquires a state of electricity contrary to that of the electrified body. If the body plunged
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in this atmosphere be of a small extent, it will be found so to all appearance, because the two extremities of a small body cannot be separately examined; whereas a body of a certain extent exhibits in a very perceptible manner the two distinct electricities. The reason of this wonderful phenomenon is to be understood by the principles adopted, and may without much attention be understood, if we suppose the excited body to be in a positive state of electricity; for in this case the atmosphere of electric fluid surrounding the excited body forces by its repulsive quality the electric fluid of the neighbouring body towards its farthest extremity, and thus accumulates or crowds it upon that extremity, from which extremity it is therefore ready to fly off upon any other body, which is of a nature to receive it, being brought near enough.

If the excited body be in a state of negative electricity, the explanation is not so obvious as in the positive case: it requires some more attention to conceive what passes. The excited body, having lost a part of its natural share of electric fluid, a kind of vacuum, if I may call it so, takes place upon this body. The electric fluid of any other body being in its natural state, and therefore in a kind of inactivity, confined as it were within its limits by the electric fluid of all the surrounding bodies, is set

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at liberty, exerts its natural repulsive quality towards that body, upon which it does not find a similar quantity of electric fluid resisting its spring, or its elastic and repulsive quality; it therefore rushes towards that kind of vacuum which exists upon a body negatively electrified; and thus the electric fluid of this body, losing its natural state of equilibrium, and accumulating itself towards the vacuum, produces there a real positive electricity, at the same time that the opposite extremity has a negative one.

Before I go farther, I must speak one word more of that particular quality of conducting bodies, by which they receive, with a kind of reluctance, either state of electricity; and, after having received it, part with the same with as much seeming difficulty. This quality, not unknown to attentive electricians, who must have observed it, has commonly appeared somewhat extraordinary and difficult to be believed by many electricians, to whom I have happened to explain my theory of the electrophore. As this quality is the foundation of this theory, I conceive it will not be amiss to demonstrate it by facts.

The first part of this inherent quality of non-conducting bodies, receiving a state of electricity with more difficulty than conducting bodies, is easily shewn by the following simple experiment: a piece of dry glass, held
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near a prime conductor, will receive no electricity, or almost none, at the same distance as that at which a piece of metal or another conducting substance will have received a considerable degree of electricity, or even a full spark.

The second part of this inherent quality may be thus demonstrated: a piece of metal insulated, as, for instance, the metal plate of an electrophore, placed upon the cake of resin excited with a considerable degree of electricity, will not receive any electricity at all, or only a faint one, when it is separated from the cake without having been touched when it was in contact with the cake, or in the sphere of action of the cake, though it was really in a state of actual electricity all the time it was upon the plate. Now, if the cake of resin did part as easily with its state of electricity as the metal plate, it would leave a considerable degree of electricity upon the metal plate; the more as it is well known that the metal does not at all resist the receiving of it.

Though it would be perhaps in vain to attempt a farther explanation of this inherent quality of non-conducting bodies, yet it will be easy to illustrate this law of nature by an example of another inherent quality in all matter, which Sir ISAAC NEWTON calls the *vis inertiae*; and is a *vis insita*, by which matter resists being put in motion, and when it is once put in motion requires as much

force to stop its motion as it required to be brought from a state of rest to that of motion.

Let us now consider attentively the state of a body situated, as I have before described, in the sphere of action of an excited electric; as, for instance, a cake of resin, a flat glass, or any other non-conducting substance; or, in other words, let us consider the state of the metal plate placed upon the resinous cake of an electrophore, supposing this cake to be excited with a positive electricity; which electricity it acquires easily by sliding the knob of a Leyden phial, charged in the common way, over its surface and by various other ways. The super-abundant electric fluid of the cake repels the electric fluid of the metal plate to its farthestmost extremity, and excites there an accumulation of that fluid; or, in other words, produces there a positive electricity, whilst it produces a negative electricity at the surface in contact with the cake.

If in this condition a conducting body be brought in contact with the metal plate, or within its striking distance, it receives a spark from it; which spark is the electric fluid of the metal plate crowded upon the extremity of the metal by the repulsive force of the super-abundant electric fluid of the cake.

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If the metal plate be touched at that side where it is really in a negative state, it will, notwithstanding, part with its accumulated positive electricity; because the repulsive power of the atmosphere of the cake will force this crowded electric fluid out of whatever part of the metal is touched, the electric fluid passing through metals very freely.

The metal plate, thus deprived of the electric fluid crowded upon it, becomes in a negative state; but the repellent power of the electric fluid of the cake continuing to act upon the metal plate, forces what remains in it towards the farthest extremity, so as to produce much the same state as it had before it was put upon the cake; so that the negative state, in which it is in reality, cannot appear but when this metal is taken out of the pressing action of the atmosphere of the cake; and therefore the metal plate being removed, by the insulating handle, from the cake, gives evident signs of having lost a part of its natural share of electric fluid; or, in other words, of being electrified negatively, the resinous cake being more tenacious of the state of electricity, which it had acquired, than the metal plate.

If the resinous cake be in a state of negative electricity, (which it acquires by a friction either with a dry hand, a piece of leather, or a rough skin; or by sliding the nega-

tive part of a charged phial upon it, or by many other ways) the contrary must happen, *viz.* the electric fluid of the metal plate, finding a kind of vacuum upon the resin cake, rushes upon it, and thus leaves its opposite extremity in a negative state.

A conducting body, having its natural quantity of electric fluid, being brought near this metal plate, gives it a spark, which spark the metal plate retains as an additional quantity. If the metal plate be afterwards separated from the cake, it must retain this additional quantity which it has received from the approaching body; because the resinous cake being, from its nature, more tenacious of the state of electricity acquired than the metal, remains thereabout in the same condition as it was before the metal plate was placed upon it; but the metal plate, having acquired an additional quantity in the time it was placed upon the cake, carries with it this quantity, and must therefore return from the cake in a positive state.

This confirms what I said before, that in the first case the cake of resin does not quit readily the electric fluid which it had acquired; and, in the second case, does not steal from the metal plate the electric fluid which it had lost.

What happens to the metal plate placed upon the resinous cake happens also to the metal upon which the resinous cake is commonly fixed; but the reverse must
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take place, that is to say, when the upper plate is taken off the cake in a positive state, the metal under the cake must be found in a negative state, if the electrophore be placed upon an electrical stand.

It may be asked, what difference there is between an electrophore and a coated phial, or a flat glass coated on both sides and charged? I answer, that there is none at all, if both or only one of the metallic coatings can be taken off by silk strings, a piece of sealing wax, or any other insulating substance. The very same day I received the electrophore sent to me by his Royal Highness the Archduke FERDINAND from Milan (which electrophore was a thin resinous cake stuck upon a flat piece of metal, to which was adapted a metal plate furnished with a glass handle to lift it up) I produced the same appearance by a common pane of glass and the metal plate of the electrophore; but soon finding that glass, however dry, quickly loses its electricity (probably from its easily attracting moisture from the air) I tried to cover it with a resinous substance, or to varnish it over with a hard copal varnish; by which means it was easily excited by friction, and retained a long while the electrical power, though not so long as the resinous cake.

I will now explain the nature of an electrophore in a manner more familiar to electricians, who understand

the received theory, by taking instead of an electrophore only a common pane of glass, adapted as a magical picture, with this difference only, that both coatings may be taken off by silk strings fastened to them, or by pieces of sealing wax. Having established a free communication between the common stock and the under coating, apply the upper coating to the prime conductor of an ordinary electrical machine, the pane of glass is charged in the common way. The prime conductor has forced a super-abundant quantity of electric fluid upon the surface next to it, by means of the coating, and as much is forced out of the opposite surface, and driven into the common stock. Open a metallic communication between the two coatings, and instantly the glass will be, as we call it, discharged: and, indeed, it is so to all appearance; but, if we examine more accurately what has happened, we shall find, that the upper metallic coating has parted, by the discharge, with all the electric fluid which the prime conductor had forced upon it, and even with that part of its own electric fluid which the repellent power of the super-abundant electric fluid, communicated to that surface of the glass by the force of charging, had driven into it; and that the under coating has recovered as much as the glass had forced through it into the common stock, and has above that acquired or absorbed that additional quantity

quantity which that surface of the glass, being brought into a negative state, had drawn from the metal itself. And thus it will appear, that the glass had, in the discharging, by no means parted with that state of electricity which it had acquired by the force of charging.

Now, glass and all electric substances receiving with more difficulty a state of electricity, and parting with it with more reluctance, the consequence must be, that, when the two coatings are separated from the glass, so as not to be in the way of absorbing or losing the electric fluid by other conducting bodies being near them, the upper coating, which was positive when the glass was charged, and nearly in its natural state, when after the discharge it remained in conjunction with the glass, must now give signs of a negative electricity, having lost by the discharge a share of even its natural electric fluid in the manner mentioned. The under coating, which was in a negative state when the glass was charged, and (like the other coating) in a natural state when after the discharge it remained in conjunction with the glass, must now, being separated from the glass, be in a positive state, because it had absorbed a quantity of electric fluid in the manner explained; which super-abundant quantity it must take with it in the moment of separation from the glass, because the glass being unwilling easily to change
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its acquired state of electricity leaves the metal without robbing it of that quantity of fluid which it had acquired.

If these two coatings, separated from the glass, are brought near one another, they attract each other; a spark ensues, because the coating, which has acquired a super-abundant quantity of electric fluid, imparts it to the other, which had lost as much; and thus a perfect equilibrium is restored between them.

If both these coatings are applied as before upon the same glass, a positive spark may be obtained from the uppermost coating, and a negative one from the other. If they are separated again from the glass, as in the first case, the uppermost coating will afford a negative spark, and the undermost a positive; and these alternate sparks may be continued a very long while.

This explanation or theory agrees perfectly with the experiments exhibited by our deceased member, the late Mr. CANTON, with elder pith balls hanging by linen threads from a wooden box, which balls are excited either negatively or positively by a piece of excited glass.

